The Aurora Line in the Spectrum of the Night Sky.

By Lord Rayleigh, F.R.S.

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§ 1. *Introduction.*

Several observers have found that the green line of unknown origin seen in the Aurora Borealis can also be seen in the sky on ordinary nights, and in comparatively low latitudes.*

Slipher, in particular, has studied the line photographically, and has succeeded in recording it with a three-prism spectrograph of 15 inches focus, thus obtaining a good measurement of the wave-length.

The present paper details further and perhaps more systematic observations on the occurrence of this line in the sky on ordinary nights. The primary object was to determine whether or not the phenomenon was to be classified with the polar aurora. If so, it might be expected that every gradation of intensity between this usually very faint effect and a bright auroral display would be met with. It might also be expected that this effect would become more pronounced as the observer moved northwards.

Other questions of interest were whether or not the intensity of the spectrum line was connected with magnetic or solar disturbance.

It does not appear that any photographs of the auroral spectrum, whether on ordinary nights or on nights of a display, have previously been made in this country.

The spectrographs used were provided with Dallmeyer cinematograph lenses working at F/1·9. These lenses have proved satisfactory for the purpose, the definition and field of view being all that was required. There is no advantage in making the collimator of short focus, and a simple achromat of 9 inches focus was used.

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* Weichert, 'Phys. Zeit.,' vol. 3, p. 366 (1902); Campbell, 'Lick Obs. Bulletin,' vol. 5, p. 46 (1908); 'Astr. Soc. Pacific,' vol. 29, p. 218 (1917); Slipher, 'Astrophys. J.,' vol. 49, p. 266 (1919).

Two instruments were constructed. No. 1 had a Rutherford compound prism, and gave a scale of 358 Ångström per millimetre near the green line, No. 2 had a simple 60° prism, and gave a dispersion about two-thirds of the previous. This scale, though small, is quite adequate to the purpose of diagnosing the presence or absence of the green line. Large relative aperture is essential to the work, and, if the prism is to be of moderate size, it entails short focal length and small dispersion. The standard width of slit used was 0·12 mm.

The plates used should be those sensitised with erythrosin, such as are supplied by most makers under the name of isochromatic or orthochromatic. These have a rather narrow but high maximum of sensitivity in the green, situated near the aurora line, and are thus very favourable for the purpose. In this connection, it should be noticed that, if too wide a slit or too small a dispersion is used, there is a possibility of mistaking this maximum in the continuous spectrum in the sky for the aurora line itself.

"Panchromatic" plates, sensitised with the various cyanin dyes (pinacyanol, etc.), are not nearly so good as the erythrosin plates for this special purpose, and much time was lost in attempting to use them.

It is always necessary to put a comparison spectrum on the plate, if only to guide the eye where to look for the green line, if present. Without such guidance, there would be constant danger of missing a faint indication, or of mistaking an accidental marking for one.

When at home, I have used a krypton tube for the comparison, the green krypton line at 5570 (which has been thought by some to be identical with the aurora line) serving for reference. When away from home, to save the trouble of carrying an induction coil, it has been found convenient to use a spirit lamp, with calcium chloride on the wick. This gives the calcium band 554, which is near enough to serve as a reference mark. The usual occulting slit arrangement was used for the comparison.

The exposure to the night sky can be begun as soon as it is dark. To avoid the necessity of being present to close the instrument before dawn, it has been found convenient to do this automatically. A photographic shutter of the roller-blind (Thornton Pickard) type is fixed in front of the slit, and should have a large enough aperture to allow of adjustment of the slit through it: otherwise the shutter must be removable for access to the slit. In any case, the cover of the slit can be shifted, after the comparison spectrum has been put on, by a forefinger, introduced through the opening of the shutter. The shutter is set open, and the lever which releases it is attached to the hammer of a cheap alarum clock by means of a thread, which is stretched by moving the clock laterally till on the point of releasing the shutter. The bell of the clock is of course removed. When the alarum mechanism works, the shutter is automatically closed.

A little easing of the mechanism of the shutter may be needed, and it may be advisable to prolong the lever of the shutter, attaching the thread to the end of the prolongation. A perfectly trustworthy arrangement can readily be made in this way. Sand clocks and water clocks have been tried, but experience has been in favour of the alarum clock as described.

The instruments were always pointed approximately to the north at an elevation of 45°.

§ 2. *Intensity in Relation to Magnetic Disturbance.*

Exposures were made every night with the Rutherford prism spectrograph (No. 1) and a Marion "Iso-record" plate from February 26 to July 3, 1921. Satisfactory records were obtained on 145 nights. In the few remaining instances the photograph was a failure from accident or inadvertence.

These photographs were used for establishing the intensity of the aurora line. It would have been more satisfactory to have some definite method of photometry instead of an eye-estimate, but, on account of the faintness of the effect, this did not seem practicable. The classification was thus:—

2 denotes a strong impression.
1 a definite though faint impression.
0 no impression of which I could be sure.

This classification is, of course, rather arbitrary, particularly as regards the borderland between 2 and 1. It was found, however, that when the whole series was re-examined without reference to the original classification, the new intensity figures assigned were nearly always the same as the old.

There are other circumstances which complicate the interpretation of these intensity figures. Moonlight within a few days of full moon gives a background of continuous spectrum, which tends to mask a feeble indication of the aurora line. Again, a stronger effect may be expected on clear than on cloudy nights. It would be very difficult to make a satisfactory allowance for this. Sometimes, however, the aurora line was of intensity 2 on cloudy nights, suggesting that the action of the clouds is rather to diffuse than to absorb the light of the aurora line; and this makes little difference, the source being diffuse already. On really dark nights the clouds are heavy enough to absorb nearly all light, whether of this kind or of any other. But such very dark nights are not numerous.

Again, the exposures were shorter during the summer months, being necessarily limited to about 4 hours at midsummer. It would be possible to limit the exposures to this at all seasons, and in a future series this should be done. But the present series was begun without any knowledge of what would be encountered, and naturally without a very definite programme. Consequently, in winter and spring the full hours of darkness were utilised for the exposure.

In spite of these various complications, it is believed that the recorded numbers indicate the daily variations of the auroral intensity well enough for a useful comparison with the degree of magnetic disturbance. This latter has been very kindly furnished to me by Dr. C. Chree, F.R.S., from the Kew Observatory records. Dr. Chree assigned character figures, 2, 1, 0, according to the degree of magnetic disturbance. The figure has reference to the general magnetic character for the eight hours centred at midnight, and thus corresponds roughly to the actual time while the exposure is proceeding.

The records for auroral intensity and magnetic disturbance are given below:—

Date.	Aurora line.	Magnetic character.
February 26	2	0
„ 27	1	1
„ 28	1	1
March 1	1	1
„ 2	0	1
„ 3	0	1
„ 4	0	0
„ 5	0	0
„ 6	1	0
„ 7	0	1
„ 8	0	0
„ 9	1	2
„ 10	2	0
„ 11	1	0
„ 12	0	0
„ 13	1	0
„ 14	2	1
„ 15	2	1
„ 16	0	0
„ 17	—	0
„ 18	2	0
„ 19	0	0
„ 20	2	0
„ 21	0	1
„ 22	0	1
„ 23	0	0
„ 24	2	1
„ 25	2	2
„ 26	2	1
„ 27	1	2
„ 28	1	1
„ 29	1	2
„ 30	0	1
„ 31	2	0
April 1	—	1
„ 2	2	0
April 3	—	1
„ 4	—	0
„ 5	0	0
„ 6	1	0
„ 7	2	0
„ 8	2	0
„ 9	1	1
„ 10	1	1
„ 11	2	1
„ 12	2	1
„ 13	0	1
„ 14	1	1
„ 15	—	1
„ 16	—	1
„ 17	2	0
„ 18	1	2
„ 19	1	0
„ 20	0	2
„ 21	0	1
„ 22	2	2
„ 23	2	1
„ 24	1	1
„ 25	—	1
„ 26	0	0
„ 27	0	0
„ 28	1	1
„ 29	2	1
„ 30	1	0
May 1	2	0
„ 2	0	0
„ 3	0	1
„ 4	0	0
„ 5	1	0
„ 6	1	0
„ 7	1	0
„ 8	1	1

Date.	Aurora line.	Magnetic character.	Date.	Aurora line.	Magnetic character.
May 9	—	1	June 20	0	0
„ 10	2	0	„ 21	1	1
„ 11	0	0	„ 22	0	0
„ 12	0	1	„ 23	2	1
„ 13	2	2	„ 24	2	0
„ 14	2	2	„ 25	1	0
„ 15	1	2	„ 26	0	0
„ 16	—	2	„ 27	1	0
„ 17	1	1	„ 28	1	0
„ 18	0	1	„ 29	0	1
„ 19	2	2	„ 30	1	0
„ 20	1	2	July 1	2	0
„ 21	2	0	„ 2	0	0
„ 22	1	1	„ 3	2	1
„ 23	1	0	„ 4	1	1
„ 24	2	0	„ 5	1	0
„ 25	1	0	„ 6	1	1
„ 26	0	0	„ 7	2	0
„ 27	2	1	„ 8	1	1
„ 28	2	1	„ 9	1	1
„ 29	0	0	„ 10	2	0
„ 30	1	0	„ 11	2	0
„ 31	0	0	„ 12	2	0
June 1	2	0	„ 13	2	1
„ 2	2	0	„ 14	0	1
„ 3	0	2	„ 15	1	2
„ 4	2	1	„ 16	1	1
„ 5	1	0	„ 17	1	0
„ 6	2	0	„ 18	1	0
„ 7	—	1	„ 19	0	1
„ 8	0	2	„ 20	1	0
„ 9	1	2	„ 21	2	0
„ 10	1	1	„ 22	0	1
„ 11	1	0	„ 23	0	1
„ 12	0	0	„ 24	0	0
„ 13	1	1	„ 25	1	0
„ 14	1	1	„ 26	2	1
„ 15	1	0	„ 27	0	1
„ 16	1	0	„ 28	1	1
„ 17	2	0	„ 29	0	1
„ 18	2	0	„ 30	0	0
„ 19	1	1	„ 31	0	0

We have to determine whether strong aurora line is associated with strong magnetic disturbance. A first glance at the figures is not favourable to such a connection.

It is desirable to eliminate the occasion of May 13–14, when there was a very great magnetic storm, and an aurora undoubtedly of the same general character as those in the polar regions, which was seen all over Northern Europe. There is no doubt of the connection in this case, but the doubt is whether the same applies to the weak auroral light photographed on ordinary nights. It may be objected that the exclusion of these two nights is arbitrary. A definite criterion to justify it may be found in the fact that on these occasions the nitrogen bands were stronger than the green aurora line, whereas they were not photographed at all on any other occasion. Whether justifiable or not, the omission of these two cases scarcely affects the statistical result.

If we classify the nights according to auroral intensity (excluding May 13 and 14), we get:—

Auroral intensity	2	1	0
Average magnetic character	0·49	0·67	0·53

There is here no indication whatever that high auroral intensity tends to be accompanied by magnetic disturbance.

If we classify according to magnetic character, we get:—

Magnetic character	2	1	0
Average auroral intensity	1·00	0·95	1·03

Again, there is no indication that magnetic disturbance is accompanied by strong auroral intensity.

§ 3 *Aurora Line and Sunspots.*

There is little doubt that the strong aurora of May 13–14, with accompanying magnetic storm, was connected with the great sunspot group which crossed the central meridian of the sun's discs on May 14–15, at a distance of only 3° from the centre of the disc. But for reasons already given when discussing magnetic disturbance, it is desirable to discuss separately the ordinary nights, when the photographs, if they showed anything, showed only the green aurora line, without nitrogen bands.

During the observations a daily watch was kept on the sun with a 3-inch telescope, the largest at my disposal, and the spot distribution roughly noted. There was nothing to encourage the idea of a direct connection, except in the one instance above mentioned. For instance, on the night of April 29 the aurora intensity was recorded as 2, but no spots whatever were detected on the sun on either April 28, 29 or 30.

The Astronomer Royal kindly supplied me with the times when spots of any importance crossed the central meridian of the sun from February 26 to July 31. These were fifteen in number and ranged in size from area 100 to 900, the unit being a millionth of the sun's visible hemisphere.

In order to determine if there was any tendency for the green aurora line to be strong near the time of transit of a spot across the sun's central meridian, the average auroral intensities were taken out as follows:—*

* When the intensity on the night of transit is referred to, the association sought is between, *e.g.*, the spot whose transit occurred on March 13 and the photographic exposure begun on the night of March 13, and finished on the morning of March 14.

Nights before transit	0·77
Nights of transit	1·15
Nights after transit	1·36
All nights observed	1·00

It will be noticed that on nights before transit the average auroral intensity was less (as it happened) than on ordinary nights. That it should be actually less is no doubt accidental, but no connection is indicated. Judging by the analogy of the auroral display of May 13–14, it is on the night before transit that the effect, if any, should be looked for. If we take the night of transit, or the night after, the line was rather more often bright than on ordinary nights. But the evidence for any connection is insufficient.

§ 4. *Geographical Distribution.*

It is obviously important to determine how the ordinary intensity of the aurora line varies with the latitude. The natural expectation would be that it would increase to the north, when it would merge into the polar aurora. I had a convenient opportunity of making observations at Beaufront Castle, near Newcastle, and took a spectrograph there in the autumn. This instrument (No. 2) had a simple 60° prism instead of the Rutherford prism in No. 1, but otherwise the optical parts were similar. No. 2 probably gave rather the brighter spectrum if anything. The plates used were from the same box as those used at Terling before and after, thus no doubt arises about their quality.*

Exposures of one night each were made on the following individual nights:—August 19–31 inclusive, September 6, September 27–October 8 inclusive, October 10, October 11. Quite a good proportion of these 28 nights were clear, but not one of the photographs gave a positive result. During the previous months at Terling, positive results were got on 101 nights out of a total of 145, and in no case was the result negative for more than four nights running.

This diminished intensity of the aurora line in a more northerly place was naturally accepted with reluctance, and although I did not see how the spectrograph No. 2 used at Beaufront could be less effective than No. 1 used at Terling, it was more satisfactory to test this point directly. This was done by taking the instrument No. 2 to Terling from September 20 to 26 inclusive. On six out of these seven nights the result was positive. The spectrograph was then taken back to Beaufront, and negative results obtained from September 27 onwards, as already recorded. Further positive results were got with this instrument at Terling in November.

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* It is my practice to cut a quarter plate into six, so that a box containing a dozen is enough for seventy-two nights.

The question arose whether the aurora line was present at all in the sky at Beaufront. A cumulative exposure was made from September 1 to 5 inclusive, and showed the line strongly. Another five-night exposure, from September 7 to 11, also showed it very definitely. These cumulative exposures unavoidably interrupted the series of single night exposures at Beaufront, which have been recorded.

It emerges then very definitely, that the aurora line, though not altogether wanting, is ordinarily less bright at Beaufront than at Terling, about 3° of latitude further south. This was a very strange and unexpected result, but, on consideration, it appeared to fit in well with the results of the Californian observers 15° further to the south.

Campbell* was able to see the aurora line whenever he looked for it. I have been quite unable to observe it visually at all at Terling, except during the display of May 13–14, though I have often looked, and have used every precaution to make the conditions favourable.

The method I prefer is to have a slit mounted in the shutter of a dark room, and to look at it through a powerful combination of direct vision prisms, which give tolerable spectroscopic purity with the slit wide. In this way, resting the eye in the dark for a time, the continuous spectrum of the night sky can be made out, and the slit may then be narrowed. I could never see the aurora line.

It may be thought inconsistent that the continuous spectrum of the night sky can be more easily *seen*, while the aurora line can be more easily *photographed*. The matter is, however, complicated by many considerations of a physiological nature, particularly the superior visibility in a bad light of an object subtending a large angle.† This favours the continuous spectrum.

Prof. Fowler informs me that he, too, has looked in vain for the aurora line on ordinary nights in the south of England. On the other hand, Prof. Michelson informs me that he has been able to see it on ordinary nights at the Yerkes Observatory (latitude 43°).

These various experiences suggest that the aurora line is ordinarily stronger in the lower latitudes, and are thus in agreement with my results for the north compared with the south of England. I hope to carry the spectrograph further south when opportunity offers.

There is no very definite means of comparing the photographic intensities

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* 'Lick Obs. Bull.,' vol. 5, p. 46 (1908), and 'Astr. Soc. Pacific,' vol. 29, p. 218 (1917).

† See my father's observations: Rayleigh, 'Proc. Camb. Phil. Soc.,' vol. 4, p. 197 (1882); 'Scientific Papers,' vol. 2, p. 92.

I obtained with Slipher's. I have compared the Cramer plates he used with the Marion plates I used, and found them of about the same sensitiveness for yellow-green light. His instrument also appears to have been similar to mine, and he obtained the line on every plate he exposed. My experience at Terling, as described, was less favourable than this, and at Beaufront very much less favourable, so that here, too, there seems evidence that the line was stronger in California, at any rate at the time when Slipher was working. Some reserve is necessary, since these various observations were made for the most part nearer sunspot maximum than my own.

The fact that I could not detect the line at all at Beaufront in one night's exposure seems to show that auroral effects could not have interfered appreciably with the observations I made there on the colour of the night sky.* I make this remark apropos of some criticisms when that paper was read.

§ 5. *General Remarks.*

There seems to be no doubt of the genuine variation of the intensity of the aurora line from time to time. Generally speaking, however, if unusually strong or unusually weak, it remains so for several nights consecutively. The range of variation at one place seems not very great, but I am not prepared at present to make any numerical estimate of it. The difficulty arises partly from the varying atmospheric conditions, partly from the "inertia" of photographic plates, partly from the extreme faintness of the phenomenon itself.

The material collected suggests that the aurora line, as photographed at Terling on ordinary nights, differs not only in degree, but also in kind, from an auroral display, such as occurs frequently in the Arctic, and occasionally in temperate latitudes. There was such a display on the night of May 13 and 14, 1921, and good photographs of its spectrum were secured. These will be reproduced and discussed in a future paper. It is enough here to remark that they were entirely distinct from any other photographs of the series, the negative bands of nitrogen, and not the green line, being the predominant feature photographically. Moreover, the intensity of the green line was a large multiple of that on any other occasion.

It would be very important to determine whether the nitrogen bands are ordinarily present in the sky. An attack will be made on this problem by long exposures with a specially designed instrument.

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* 'Roy. Soc. Proc.,' A, vol. 99, p. 10 (1921).

§ 6. *Experiments Bearing on the Origin of the Green Aurora Line.*

Slipher's investigations (*loc. cit.*) gave a wave-length of 5578 for the green aurora line. This differs considerably from the old value 5570 which led some authors to identify the aurora line with krypton, and leaves little doubt that the krypton origin must be abandoned. It is, however, satisfactory to make the comparison directly, and this was frequently done in the present work, the krypton line being used for reference as already described. Many plates were obtained suitable for testing the coincidence or otherwise of the aurora line with krypton, and they all showed that krypton was the less refrangible. The photographs were not on a large enough scale to measure closer than about 3 Ångströms, but within these limits the result was consistent with Slipher's.

The auroral display of May 13–14 gave the same results, thus there is no reason to doubt that the line found in the sky on ordinary nights is really the same as the line seen in auroral displays. The consistent statement of many experienced visual observers that the (brilliant) aurora gave a wave-length of about 5570 led to some reasonable doubt on this point, for the error they made is greater than would have been supposed possible.

My colleague at the Imperial College, Prof. A. Fowler, F.R.S., has examined some of the photographs of both kind and allows me to state that he concurs that they clearly prove non-coincidence with krypton. The supposed krypton origin is, therefore, to be discarded. In any case it was obviously very difficult to imagine how so dense a gas could be concentrated in the upper atmosphere.

Although the aurora *line* is usually spoken of, it is quite possible that what we observe is the bright head of a band. It is only by the use of high resolving power that this possibility could be excluded. Since bands may be due to molecular complexes (*e.g.*, ammonia, water vapour, magnesium hydride) the field of search for a possible origin is somewhat widened by this consideration. I shall, for brevity, speak of the aurora line without intending to exclude the alternative.

In a former investigation* it was shown that ozone must be present in the upper atmosphere, and possibly at a high concentration. This, together with the great altitude of the aurora found by Stormer† suggested that the green line might be a fluorescence spectrum of ozone, excited perhaps by the ultra-violet light of the negative nitrogen bands, which appear concurrently on the aurora.

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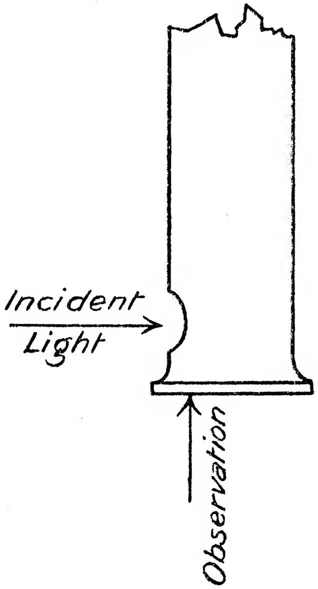
* 'Roy. Soc. Proc.,' A, vol. 94, p. 260 (1918).

† 'Kristiania Vid.-Selsk. Skr.,' I, M.-N.Kl. (1911), and later papers.

The ultra-violet light from an iron arc was separated from visible light by R. W. Wood's method of focal isolation* using quartz lenses. This method consists, in brief, in focussing on a small hole an ultra-violet image of the source. The ultra-violet light gets through the hole, while visual light, which is not in focus is for the most part stopped.

The ultra-violet light was collected by another lens and focussed on a quartz vessel containing ozone. The ozone was prepared by Goldstein's method of vacuum discharge at low temperature.† As ultra-violet light is intensely absorbed by ozone, the fluorescent effect, if any, should be very close to the window where the light enters. The latter accordingly took the form of a dimple, sucked inwards in the quartz vessel. A clear silica window, fused on, allowed of easy observation at right angles to the incident light (see figure).



No fluorescence whatever was observed under these apparently favourable circumstances, either with the ultra-violet light from the iron arc, the entire radiation of the iron arc, visual and ultra-violet, or the cadmium spark.‡

The presence of concentrated ozone was verified after the experiment by passing an induction spark through the vessel. The ozone was decomposed with an audible click, and a bright flash passed down the tube. I looked to see if the aurora line was present in this flash. Only the sodium line could be observed, however.

The negative glow of a discharge tube containing oxygen shows a spectrum of four rather broad and more or less symmetrical bands without sharp heads. Prof. Fowler pointed out to me that the centre of the brightest of these was not far from the aurora line. It occurred to me as worth trying what would be the aspect and position of this band if produced at low temperature, such as may prevail in the auroral layer. An oxygen discharge tube was accordingly immersed in liquid air, but no tendency of the band to become narrow or to approach closer to the position of the aurora line was observed.

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* 'Physical Optics,' 1911, p. 415.

† 'Ber. Deut. Chem. Gesellsch.,' vol. 36, p. 3043 (1903).

‡ Hartley, 'J. Chem. Soc.,' vol. 63, p. 250 (1893), described a blue fluorescence of ozone illuminated by the cadmium spark. I have not succeeded in seeing this, though I had the advantage of being able to concentrate the ozone by liquefaction.

It is worth while to mention that the oxygen band is conspicuous under certain circumstances in the cathode ray spectrum of air at low pressures. It is, I believe, generally supposed that the cathode rays in air show nitrogen bands only.

I have recorded these negative results in the hope that they may suggest something more successful to a future investigator.

§ 7. *Summary.*

(1) The spectrum of the night sky at Terling (not far from London) has been photographed systematically. The aurora line at wave-length 5578 is recorded on about two nights out of three.

(2) Its intensity on ordinary nights does not seem to be obviously related either to the amount of magnetic disturbance, or to the transit of spots over the sun's central meridian.

(3) The intensity in the neighbourhood of Newcastle is notably less than near London, thus the effect appears to increase towards the south. It would seem, therefore, to be due to some different cause from the Polar aurora.

(4) It is confirmed that the aurora line does not coincide with krypton. Some experiments to determine its origin are described, but the results are negative.